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ETL-0534

Expert System for Minefield Site Prediction

Phase II Final Report

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This report reviews the major system components of the MSPES and discusses modifications made to the system under Phase II of this contract. Phase II development grew out of the prototype system developed under Phase I. A high-level description of the software architecture was presented in an earlier document [Barth et al, 1987], with a more detailed description presented in the Phase I Final Report [Dillencourt et al, 1988]. The scope of Phase II was the development of a "complete expert system for minefield site prediction." Phase II MSPES development continued on the Sun 3/160 at the request of ETL. The transporting of the system to the target computer, a VAXStation II GPX, was scheduled for Phase III. Phase II effort was concentrated in two areas: first, the implementation of the user interface using the X Window System graphics package, and secondly, in expanding the knowledge base of minefield doctrine.

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PREFACE

This report describes the work performed under Phase II of Contract DACA72-86-C-0017 for the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, by PAR Government Systems Corporation, Reston, Virginia. The contracting officer's representative was Mr. John Benton, CEETL-RI-I.

1. Introduction

This report describes work performed during the period from February 1988 through January 1989 under Phase II of contract DACA72-86-C-0017, Expert System for Minefield Site Prediction.

1.1 Scope of the Report

This report reviews the major system components of the Mine Site Prediction Expert System (MSPES) and discusses modifications made to the system under Phase II of this contract. Phase II development grew out of the prototype system developed under Phase I. A high-level description of the software architecture was presented in an earlier document [Barth *et al*, 1987], with a more detailed description presented in the Phase I Final Report [Dillencourt *et al*, 1988].

The organization of this report is as follows. Section 2 provides an overview of the system. A description of the various components is presented in Section 3. Section 4 contains some recommendations based on evaluation of the Phase II developments.

1.2 Scope of the Phase

The scope of Phase II was the development of a "complete expert system for minefield site prediction." Phase II MSPES development continued on the Sun 3/160 at the request of the ETL. The transporting of the system to the target computer, a VAXStation II GPX, was scheduled for Phase III. Phase II effort was concentrated in two areas: first, the implementation of the user interface using the X Window System graphics package and, secondly, in expanding the knowledge base of minefield doctrine.

1.3 Summary of Work Performed

The major results of the work performed under Phase II were the following:

• *User interface implementation* . The user interface implementation under Phase I, the prototype MSPES was with SunView, a proprietary software package of Sun Microsystems Inc. To make the MSPES more transportable to other machines, the user interface under Phase II was implemented using the X Window System (X11), a graphics package originally developed at the Massachusetts Institute of Technology (MIT).

• *Rule base development.* The knowledge base expansion in the latter stages of Phase II was significant. This knowledge will be incorporated into the rule base under Phase III. The two rule base approach decided upon in Phase II will be reviewed with respect to the additional knowledge.

• *Enhancements to QUILT.* QUILT, licensed Geographic Information System (GIS) software developed at the University of Maryland Center for Automation Research, was enhanced in several ways to improve performance of the MSPES. These modifications included improvement to the reporting of error conditions and the ability to support larger collections of linear information including attribute information.

• *Spatial Processing.* Under this phase the concept of channelized movement, or areas where traversal of the terrain is constricted by natural barriers, was substantially expanded. Instead of the previous local processing routine used to identify these narrow passages, a global spatial processing routine involving skeletonization was used.

2. Overview of the System

The goal of the MSPES is to automate some of the functions performed by the terrain analyst and the combat engineer in the determination of potential minefield sites. The factors used in minefield site prediction include terrain information, such as cross country mobility (CCM) information; mine and countermine warfare doctrine, as found in military training manuals; and battlefield situation or enemy intention knowledge, as supplied by battlefield intelligence. Developing the MSPES involves elements of military terrain analysis, which in turn encompasses both geographic analysis and military doctrine. The system therefore comprises a geographic information system (QUILT) for handling the terrain information; an inferencing mechanism (ERS) for coordinating rules about how the doctrine exploits the terrain information in making minefield site predictions; and a direct manipulation user interface based on a windowing graphics package (X11) to provide the analyst working in this domain with a consistent, intuitive environment.

The individual system components were previously discussed in the Phase I Final Report [Dillencourt *et al*]. Phase II modifications and enhancements to the system components are discussed in detail in Section 3. In this section, a scenario is presented that describes how manuscripts are created. The scenario illustrates the interactions among the system components.

2.1 An Illustrative Scenario

The terrain overlays associated with an Area of Interest (AOI) and a rule base are the necessary inputs to start the process in which the ERS inference engine may run. The textual rule base that the analyst has selected is read from a disk file and is compiled. The compiled rules become the inference network for ERS. The inference network drives the process of gathering evidence for the various hypotheses about a location being a mine site.

Locations to be evaluated are specified to ERS by the **Create Manuscript** application or the **Explain Manuscript** mode of the **View Map** application. The **Create Manuscript** application gets its AOI locations from a geographic primitive, whereas the **Explain Manuscript** mode of the **View Map** application gets its AOI locations from the analyst interactively. Because of the way AOI locations are identified, they are guaranteed to have an homogeneous mobility category.

The evidence in support of ERS's inferential hypothesis comes from GIS primitives. The primitive processes that ERS uses are started as needed following the compilation of the inference network. The relationship of the terrain characteristics relative to a location provide evidence to ERS. ERS uses this evidence as the basis for an evaluation of the likelihood of the location being a mine site. The evidence in support of the possible hypotheses is evaluated and the hypothesis with the highest 'score' becomes the evaluation for the specified location.

The **Create Manuscript** application sends this evaluation back to the geographic primitive that initially reported the location coordinates. This primitive updates the value associated with the location to reflect the mine site likelihood evaluation. Since the data base file used for this purpose is never accessed by ERS, this evaluation does not bias later evaluations. The **Explain Manuscript** mode of the **View Map** application reports the evaluation and related rule base information to the analyst through a window-based interface to ERS. The analyst may review the evaluation in terms of the evidence compiled supporting the hypothesis and the inferencing process and may choose to edit the manuscript, edit the rule base, or to accept the evaluation.

3. System Software Description

The Phase II MSPES software components are organized as shown in figure 3-1. MSPES Applications, the Inference System, and the Geographic Information System access rulebases, terrain data, and map descriptions which are defined in disk files. MSPES Applications and the Inference System have user interface components which use Window System Interface routines to present textual and graphic displays to the user. MSPES Applications, the Inference System, and the Geographic Information System communicate data amongst themselves as each requests it. The MSPES Applications and the Inference System communicate with the GIS via GIS primitive processes, each of which answers simple queries of the data base maintained for an Area of Interest. This overall organization is fundamentally the same as that used for the prototype MSPES. The succeeding sections will discuss the major modifications to the prototype MSPES.

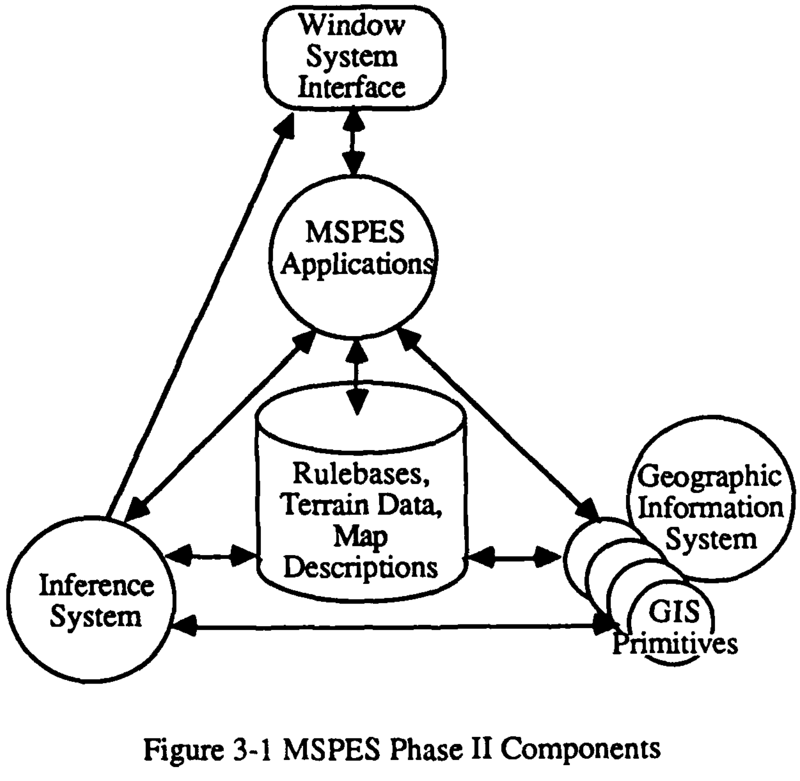


Figure 3-1 MSPES Phase II Components

3.1 Input Conversion

The Phase II MSPES uses two basic types of information to support its rule base evaluation of terrain characteristics: vehicle mobility data derived from the Condensed

Army Mobility Model System (CAMMS) and transportation network information derived from ADDWAMS transportation features.

3.1.1 CAMMS processing

CAMMS data is imported to the system as a textual representation of a raster of speed values for a particular vehicle type across the terrain of a map sheet given specified weather conditions. The MSPES **camms_binary** process converts this mobility speed map into a quadtree by first converting the textual format to a raster of binary integer values. The **ccm_cvl** process then converts the mobility speed values into mobility categories (go, restricted, slow, etc.) as the raster is converted into the input format used by the QUILT package. The default mobility category breaks are easily over-ridden at run time to assign different speed values to the mobility categories. The mobility categorized CAMMS data is converted to an areal quadtree using the QUILT **build** procedure. The resultant mobility quadtree is used directly by the Inference System as well as indirectly via the derived overlay of channelized areas. Figure 3-2 illustrates the processes used in converting CAMMS mobility information into a mobility category quadtree.

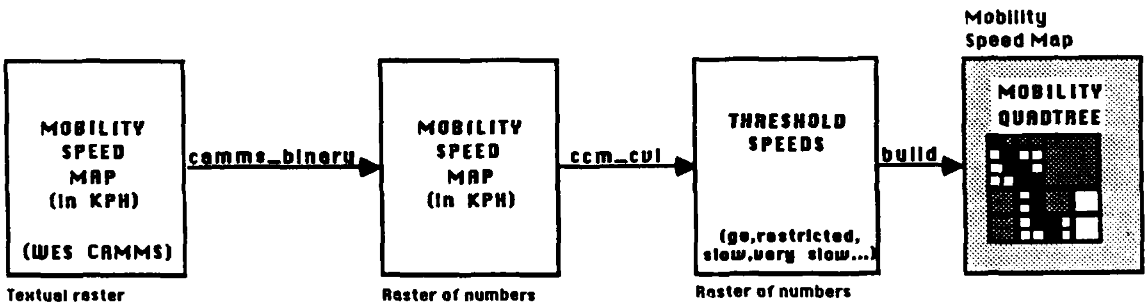


Figure 3-2 - Conversion of CAMMS data to Mobility Quadtree

3.1.2 ADDWAMS processing

The Phase II MSPES derives transportation feature information from linear descriptions of transportation features in ADDWAMS format. Two processes are used to convert data in this format to the formats used by the GIS. The first process, **cnvrtadw**, converts the ADDWAMS format data to the input format used by QUILT. At the same time, the feature header information is extracted from the ADDWAMS format and saved separately. The linear feature descriptions resulting from this procedure are then converted into a PM quadtree via the QUILT procedure **pmbuild**. The feature ids are maintained in the PM quadtree. The feature headers, sorted into increasing order by feature ID if

necessary, are accessed by MSPES software by keying on the feature ID values. Figure 3-3 illustrates the procedures of converting the tranportation feature descriptions into the data formats used by the MSPES.

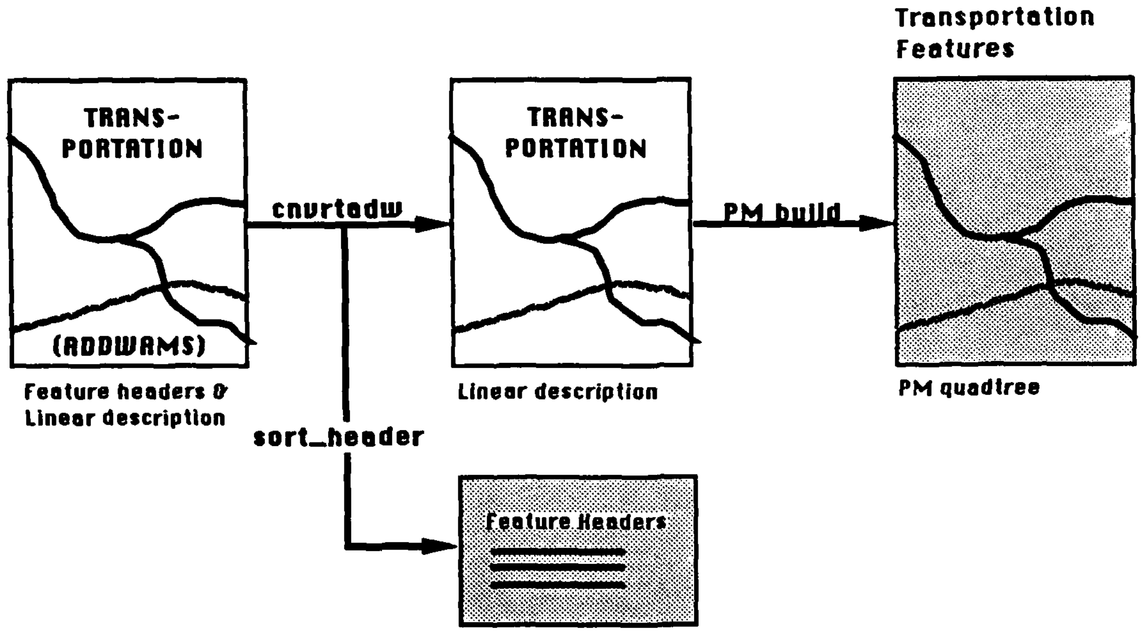


Figure 3-3 Conversion of ADDWAMS format data into PM Quadtreee

3.2 Inference System

The Inference System that is used by the MSPES is ERS, the Embedded Rule-based System. ERS is run as a separate process by the MSPES applications that require access to the Inference System. ERS, in turn will start separate GIS Primitive processes corresponding to the pieces of geographic information that a rule base requires.

3.2.1 Primitive Management

During Phase II, modifications were made to the way ERS manages its Geographic Information System primitive processes. Previously, the ERS Primitive manager started all of the primitive processes during the first initialization call. Not all MSPES rule bases use the same set of GIS primitives, however.

During Phase II development it was decided that the manuscript creation process could be improved by evaluating all of an area of interest to determine the possible minefield sites using one rule base based on terrain knowledge, then using a second rule base incorporating battlefield information to further categorize the possible minefield sites

resulting from the first rule base. Since the MSPES rule bases use different sets of GIS information it was necessary for the primitive manager to be able to manage different sets of rule base primitives. The primitive manager was modified so that GIS primitive processes are started when information required of them is first requested during rule base evaluation. Once initialized, the GIS primitives are kept active until rule base evaluation is complete.

3.2.2 Rules

The purpose of the MSPES rule bases is to determine the likelihood of a minefield being present at a certain location. Four categories of likelihood are assigned: *Very Likely*, *Likely*, *Possible*, and *Unevaluated*. Each one of these goals is represented by a separate rule base goal node.

Two rule bases were developed under Phase II. Rule base one contains rules incorporating information on terrain factors affecting minefield doctrine. The result of inferencing based on this rule base is an interim product, the terrain-based minefield manuscript. For a given area, this product would not need to be regenerated unless there is a dramatic change in terrain or in minefield doctrine as it applies to that terrain. Rule base one categorizes the terrain of an area of interest into one of the three categories *Likely*, *Possible*, or *Unevaluated*.

Rule base two contains information which accommodates enemy intention and battlefield situation data. Because of the dynamic nature of this data, this second rule base might be run, updated, and run again. To avoid having to repeat inferences involving static terrain characteristics whenever there is a change in battlefield situation, the information is partitioned into the two rule bases. This reduces the time consuming inference processing by reducing the number of rules in the rule base which will be repeatedly run. Rule base one can be viewed as a pre-processing step while rule base two can be viewed as the main process which will be repeated given changing parameters. The terrain-based minefield manuscript produced by rule base one is input for processing rule base two. Rather than firing rules to determine a location's minefield site likelihood based on terrain factors alone, rule base two uses the output from rule base one in a table look up operation.

3.3 Geographic Information System

During Phase II developments, modifications were made in the way the Geographic Information System, QUILT, is used. The architecture of GIS usage by the Phase II

MSPES remains the same as that used in Phase I: some GIS 'primitives' are used to feed information to MSPES application programs and update the data base while other GIS primitives are used by the Inference System to provide information about terrain characteristics in support of rule base evaluation. The modifications were in two areas: the way applications use GIS 'primitives' to feed them information, and the GIS primitives used by the Inference System.

3.3.1 Application Use of GIS

Previously the MSPES used slight modifications of the native QUILT capabilities to drive the display of terrain information. Two modifications were made to improve application performance using the GIS. The display of areal quadtrees is now significantly faster. Previously areal quadtree display was achieved by traversing the quadtree and issuing a display command for each quadtree leaf node, specifying its upper left corner coordinate and the size of the leaf node. This resulted in large numbers of display commands being issued to the window system, ultimately creating a raster image of the quadtree. Experimentation showed that significant performance improvements could be gained by using adaptations of QUILT code to convert the quadtree to a raster directly and then pass the raster to the window system. Additions were made to the **qdisplay** process to accomplish this quadtree to raster conversion process and to pass the resultant raster to the application requesting it in a more efficient manner than is done for individual quadtree leaf nodes. (The latter method of display is still used for linear information stored in PM-quadtrees.) In addition, modifications were made to the window system interface to perform raster replication to increase the scale of area of interest displays.

Several modifications were made to the QUILT system itself at PGSC's request through a subcontract with the University of Maryland's Center for Automation Research, the developers of QUILT. These modifications were in three areas: 1) Support for the storage and retrieval of attribute data in PM quadtrees; 2) Support for the buffering of access to the segment array used to associate PM quadtree nodes with line segment identifiers; and 3) Making all error messages go to the standard error file.

Support for the storage and retrieval of attribute data was requested to permit the use of larger collections of linear information. QUILT stores linear information by recording the intersection of each pair of linear feature coordinates with the boundaries of quadtree leaf nodes. Associated with each two point segment is an internal QUILT identifier that can then be used to look up an associated attribute. For MSPES purposes,

the attribute associated with these internal identifiers is a feature ID that can, in turn, be used to look up the full collection of attributes associated with, for example, transportation features.

The modifications to support storage and retrieval of attribute identifiers necessitated additional modifications to the way in which QUILT associates these internal identifiers with application attribute values. Modifications were made to buffer the access to the array mapping internal, segment identifiers to feature identifiers. Prior to these modifications, QUILT maintained the array as an in-memory look up table. Subsequent to the modifications, QUILT buffers its access to a disk file-based look up table, maintaining only a small portion in memory at any one time.

In coordination with these modifications, attribute look up mechanisms were added to MSPES applications to enable them to associate linear feature identifiers with their attributes. This permitted the display of PM-quadtrees to be color keyed to the types of transportation network features, and allowed GIS primitives interested in road features to isolate road features from other aspects of the transportation overlay.

The isolation of error messages was requested to support the means by which application programs receive information from GIS primitives. In the current MSPES interprocess communication scheme, GIS primitives simply write requested information to their standard output. Prior to the isolation of error messages, some QUILT errors were written to the standard error, while others were written to standard output. PGSC requested that the error messages be consistently written to standard error so that applications could reliably depend on getting requested information only from the standard output. With this modification, applications were not liable to misinterpret an error message as GIS information.

3.3.2 GIS Primitives used by Inference System

A variety of modifications were made to the GIS primitives used in rule base evaluation. Two significant changes were in the primitives used to determine whether an area's terrain tends to channel movement, and the primitives that determine distance to road network features.

As discussed in the Phase I report, the MSPES uses the concept of an area tending to channel movement into relatively narrow passages by constraints of the terrain. The prototype system's determination of whether an area had evidence of channeled movement

was, on evaluation, too simplistic and heavily influenced by the underlying quadtree data structure. During Phase II, software was developed that uses the characteristics of the terrain to better determine whether an area tends to channel movement. The process by which this determination is made requires several steps. First, selected categories of vehicle mobility are extracted from the mobility overlay using the QUILT **subset** function. By default, all mobility categories that permit vehicle traversal: go, restricted, slow, and very slow, are used. The QUILT **binary** function is used to convert these categories into an overlay that distinguishes traversable areas from areas of no mobility. The QUILT **raster** function converts the resultant quadtree to the format used by the skeletonization process. The MSPES **skel** process 'skeletonizes' the raster. The skeletonization process, based on the Zhang and Suen thinning algorithm, iteratively processes the raster, thinning mobility areas until they are at most one pixel in width. As this thinning takes place, the skeletonization process remembers on what iteration each mobility area reached a single pixel width. This skeletonization process results in a network of single pixels representing the center lines of the mobility areas.

It is important to note that the center lines that result from the skeletonization may or may not correspond to real terrain features. Areas that required many iterations to be thinned to a single pixel simply correspond to the center line of large, homogenous areas. The position of the skeleton network through these areas probably has no great significance to terrain traversal other than to denote the connectivity of traversable areas.

The areas that were thinned in only a few iterations of the skeletonization process, however, generally correspond to real features of the terrain: gorges or levees for example. By extracting the subset of the network that were thinned in a threshold number of iterations, using the **threshold** process, and expanding them to the threshold distance, using the QUILT **within** function, we can create a mask that corresponds to the areas that do exhibit characteristics of a canalized area. 'OR'ing this mask with the original traversable areas overlay derives areas that exhibit characteristics of channeled movement. All of the preceding steps are carried out prior to rule base evaluation. The rule base primitive that answers the question: "Does this area enforce channeled movement?" simply looks at the derived channelized areas overlay to determine whether the location in question does or does not correspond to an area that exhibits the channeled movement characteristic. Figure 3-4 depicts the procedures that transform the mobility quadtree into the channelized areas overlay. Figure 3-5 illustrates the process as applied to a small area of mobility data.

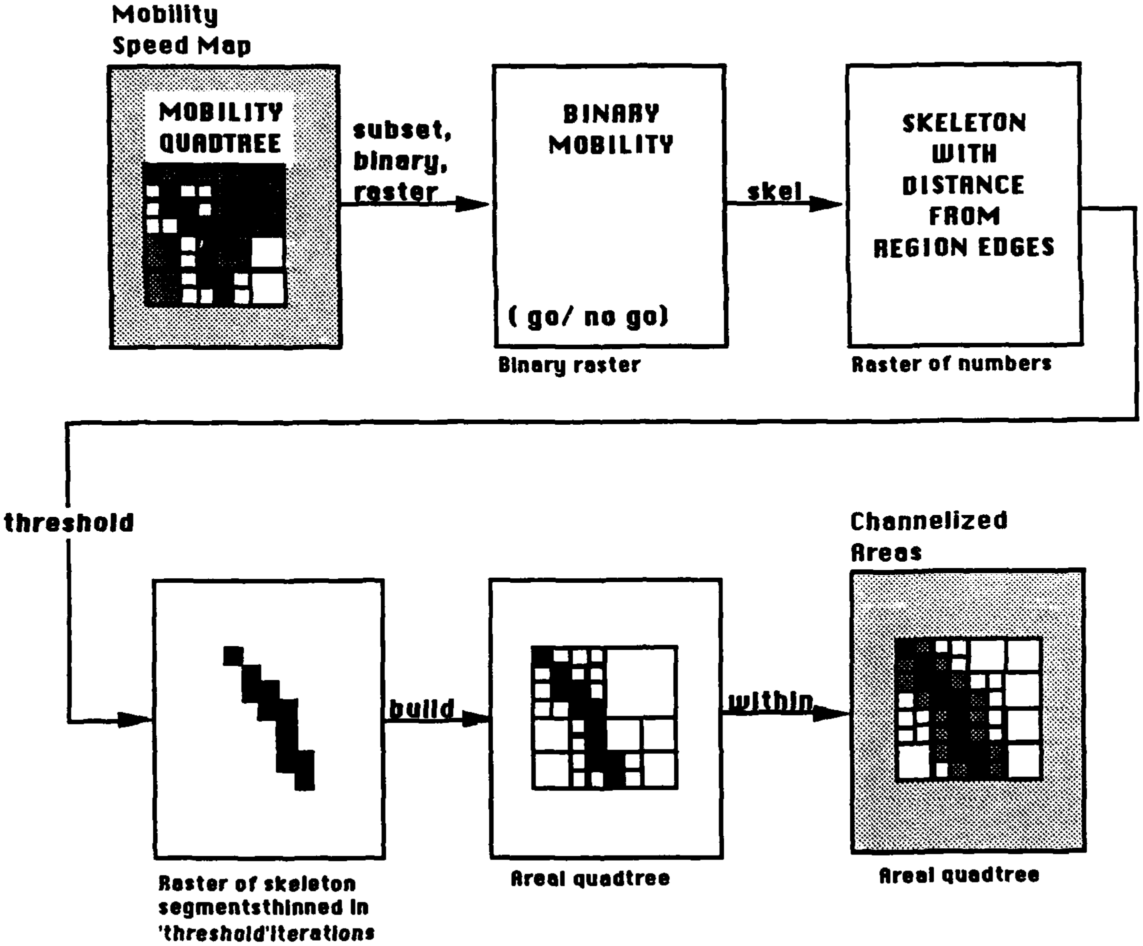
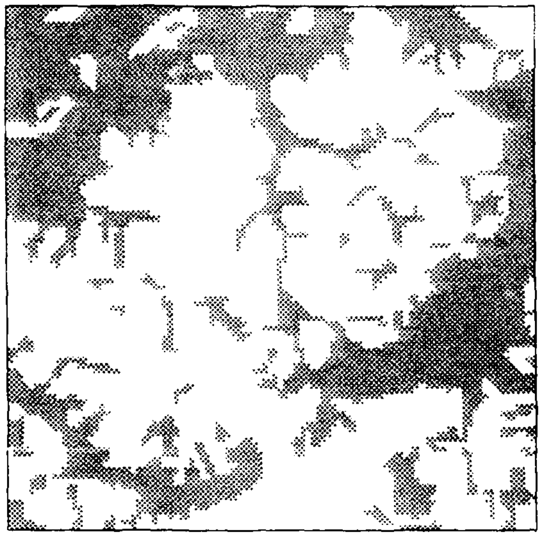
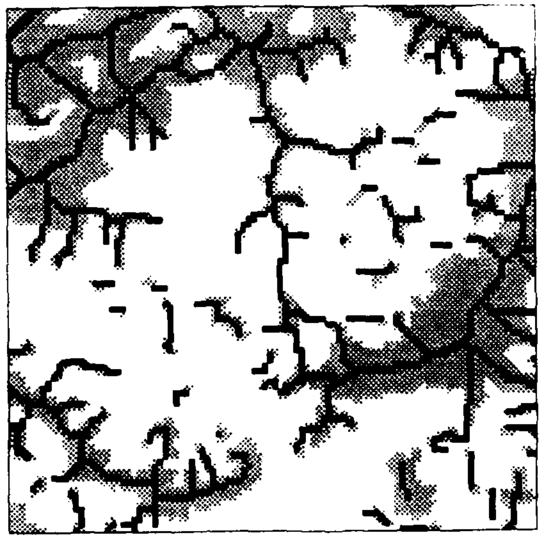


Figure 3-4 Conversion of Mobility Quadtree into Channelized Areas

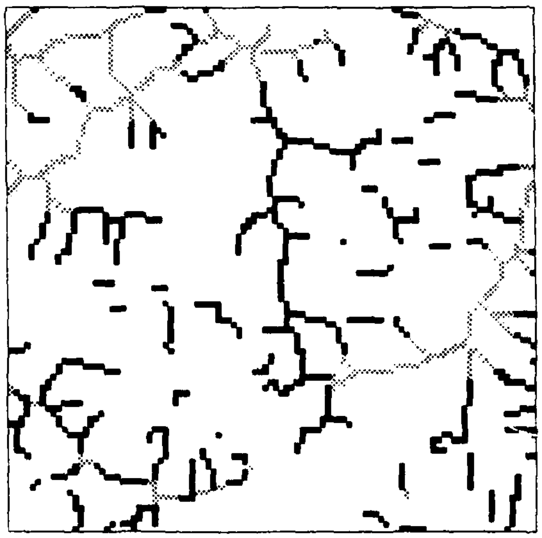
Another GIS primitive used by Phase II rule bases is one that answers the question: "Is this location within 3 kilometers of a road?" The primitive that answers this question is different in a number of ways from the road distance primitive developed for the Phase I rule base. First, it uses real world distances, measured in kilometers, whereas the previous road distance primitive used only quadtree units. Information derived from the input mobility data permits the mapping from real world units to quadtree units. Second, using the modifications made to QUILT to enable linear feature identifier look up, the 'road within 3 kilometers' primitive can restrict itself to investigating in detail only road features within the threshold distance.



Traversable Areas



Skeleton of Traversable Areas



Segments Thinned in Threshold Iterations

Channelized Areas From Skeleton Segments

Figure 3-5 Determining Channeled Movement Areas from Areas of Mobility

3.4 Window System Interface

One of the goals of Phase II MSPES development was to ease the transition of the user interface portion of the MSPES to the Phase III target system, a VAXStation II/GPX running the VMS operating system. To that end, it was decided that the user interface used by MSPES applications would use a non-proprietary, portable window system graphics package: the X Window System.

3.4.1 The X Window System

The X Window System, originally developed at MIT and now under the control of a consortium of commercial vendors and educational institutions, defines a portable protocol for creating window-based user interfaces on high performance workstations in a networked environment. The X Window System uses a client-server model to generate application user interfaces. Application clients, running on any machine on a network, use X library calls to generate the X protocol. An X Window server, running on the user's workstation, receives X protocol message packets via the network, interprets those message packets, and generates the user interface windows for all applications' graphic displays and dialogues with the user.

The C Language binding of the X library, the X Toolkit, and the Athena 'widget' set, together compose the basic components of the public domain, sample X implementation available from MIT. When MSPES Phase II development started neither the Sun workstation, prototype system platform, nor the VAXStation II/GPX had a native implementation of the X Window System. Both vendors, as well as many others, had announced products that would support X Window System servers for their machine architectures and operating systems, however. The Phase II MSPES uses the X Toolkit and Athena 'widget' set to create the components of the user interfaces employed by MSPES applications. The X Toolkit is the higher level, programmer's interface to the X protocol, and defines a standard, object-oriented approach to creating user interfaces. The Athena widget set provides the baseline functionality to support a variety of application environments. The Athena widget set, while not part of the X Window System standard, will probably become the basis for the baseline functionality required of a widget set. It is anticipated that the DECwindows widget set to be used for Phase II development will be a superset of the Athena widget set because Digital Equipment Corporation had a significant influence on the development of X, the X Toolkit, and the Athena widget set.

The X Toolkit and the Athena widget set provide nearly the same functionality as the proprietary SunView user interface toolkit that was used during Phase I prototype development. Converting the MSPES user interface to an X implementation was a relatively easy task. To facilitate the eventual transition to a DECwindows environment on the VAXStation II/GPX, a separate layer of window system interface routines was added to the MSPES configuration. This Window System Interface layer isolates the MSPES application code from the details of the window system interface used to define the user interface.

3.4.2 Application Control Panels

Each of the MSPES applications: **View Map, Create Manuscript, Input Map, Edit Rulebase,** and **MSPES Help** has a control panel. These control panels consist of command buttons and ancillary label information such as the name of the current Area of Interest, the current manuscript, etc.

The Phase II MSPES control panels consist of a vertical array of buttons and labels. This arrangement has several benefits: First, the vertical arrangement is similar to the ALBE testbed user interface. It is an important aspect of user interface design, particularly of applications which use direct manipulation interfaces, that the user interface match the user's conceptual model. The MSPES uses a portable window system to create a familiar looking environment in which to perform interactions with geographic information. The ALBE testbed equivalent to the MSPES control panels are the command menus which appear on the alpha-numeric terminal and the control, message, and legend areas that appear along the right margin of the ALBE graphic terminals. Secondly, the arrangement of components within application windows is automatically maintained by components of X Toolkit widget sets, no MSPES code had to be developed to create this arrangement. The form widget permits child widgets, the buttons, labels, and graphic canvases used by the MSPES, to specify relative positioning hints to the parent form. These hints allow the child widgets to maintain their relative positions after resize events caused by the user modifying the application window arrangement. Finally, the default position for the MSPES control panels is along the right hand side of the graphics display rather than along the top as was used for the Phase I system. By positioning the control panel along the sides of the graphic terminal a larger, squarer area is left free for the graphics display.

Command buttons on application control panels sometimes appear 'grayed out' and cannot be selected by the user. This is controlled by the need to satisfy prior conditions

before the command can be applied. For example, the DISPLAY MAP button appears grayed out on the **View Map** application control panel until the user has selected a map using the LIST MAPS button. In this way the user is led through the process of using the application without having to remember a particular command sequence.

Application control panels are defined and manipulated using a package of functions that serve as an intermediary between the applications' user interface definition functions and the functions that actually create the user interface components. The purpose of having this set of intermediary functions is twofold: 1) to insure that common functions are used between MSPES applications, and 2) to insure that multiple MSPES applications use the same user interface structures, button names, and labels to produce similar actions.

Legend information is displayed below the control panel, similar to the location of the legend box used in the ALBE testbed. The handling of the legend display is accomplished with a package of routines that manipulate the legend contents in a manner transparent to the rest of the applications.

Another function package manages the interface to information about Areas of Interest. This encapsulation of AOI information isolates MSPES applications from the details of how AOIs are maintained.

Similarly, a library of routines was developed to isolate MSPES applications from the way geographic information is stored and the distinction between overlays and manuscripts. A benefit of the encapsulation of map information is the ease with which new components of geographic information can be incorporated into the system.

3.4.3 Graphic Viewport

The graphic viewport is where maps and manuscripts are displayed for MSPES applications that use them. The Phase II user interface displays the graphic viewport to the left of the control panel in an area that, by default, uses most of the screen real estate.

Graphic viewports are implemented using a simple widget created for MSPES applications. This widget is implemented by the routines in the Gwindow library. A Gwindow widget object provides methods for drawing text, lines, polygons, points, and displaying rasters, among other capabilities. The implementation of these functions is hidden from applications and is readily modified to effect performance or functional improvements.

Figure 3-6 depicts the Phase II **View Map** application user interface, illustrating all the components referred to above.

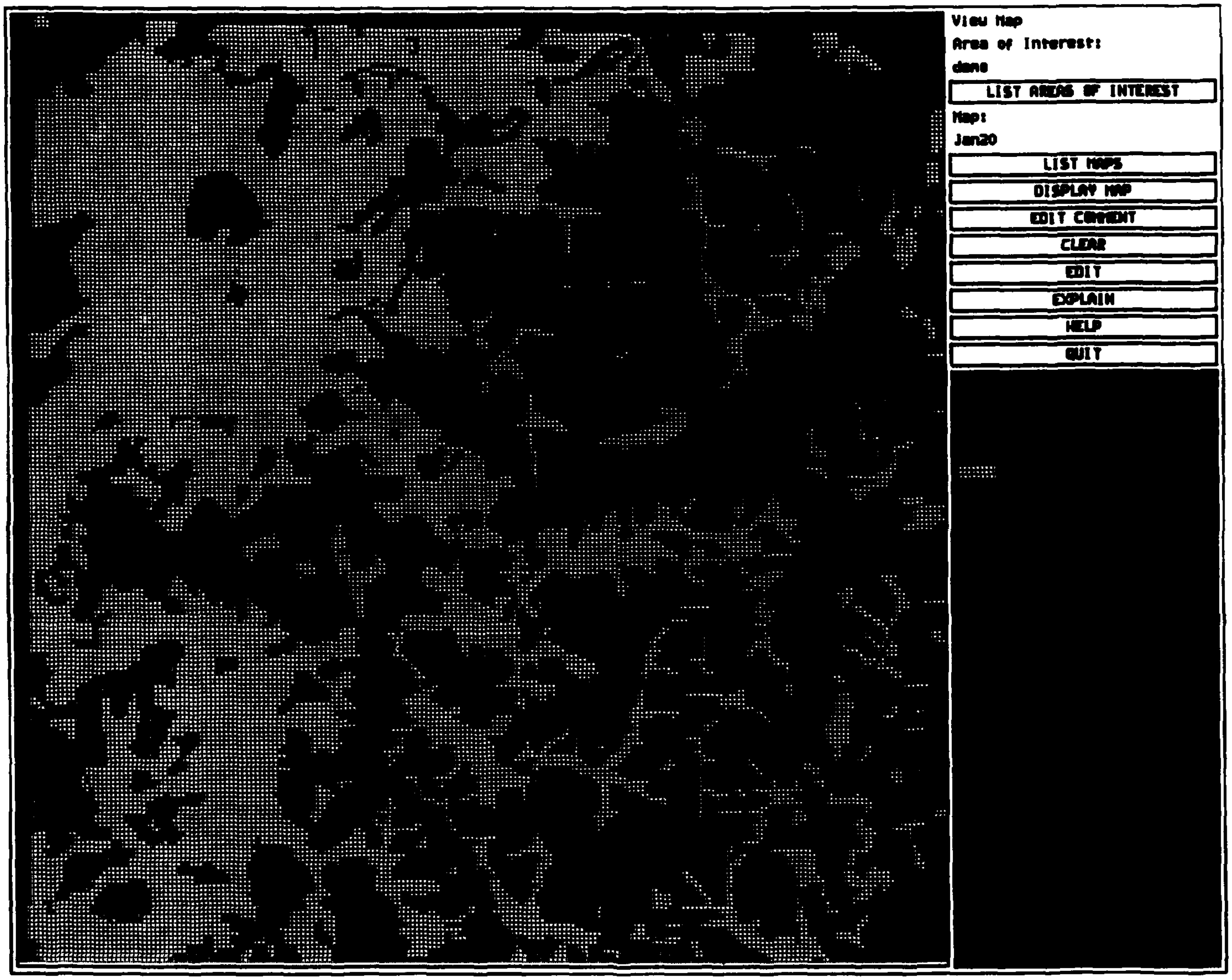


Figure 3-6 MSPES View Map application

3.5 User Interface

Under Phase II development a number of modifications were made to the user interface used by MSPES applications to facilitate customization to user requirements and modification to the graphic appearance of applications.

Several MSPES applications make use of native operating system capabilities, facilities presumably familiar to a user, to accomplish the tasks of text editing and viewing help screens. The user may modify the operating system utilities used to accomplish these tasks by changing operating system environment characteristics. Under the Unix operating system, this is accomplished by setting environment variables, a task usually performed in the user's .login or .profile file. Under the VMS operating system, the same effect is accomplished by setting logical names, often performed in the user's LOGIN.COM file. The MSPES uses default values for the various environment variables it makes use of. The user is free to over-ride these default values by setting up the user environment differently before MSPES applications are started. Using this mechanism, the MSPES will employ the user's preferred text manipulation tools.

The X implementation of the MSPES control panels permits some of the appearance of the user interface to be customized readily by the user. This customization is accomplished by specifying resource strings in an .Xdefaults file or by loading resource definitions into the window system server. Using these application resource specifications, the user can modify what font is used for command buttons and labels in the control panels, the width of borders, the color of borders, etc. The initial position and size of the MSPES user interface windows is likewise determined by resource definitions that the user is free to over-ride with private specifications.

The colors used to depict information on map displays and legends, and the legend text associated with each type of map used, is stored in a text file that is read and interpreted when the applications start a new map display. These text files can be modified by the system manager to reflect desired color or legend text changes. Currently this information is common to all users, and is not custom-made on an individual user basis unless the user duplicates all the ancillary files used by the system and over-rides the system default environment variable that determines the file system location for this data. Under Phase III development it is anticipated that map color information will use the resource specification method to eliminate the run time interpretation of the map colors and facilitate individual customization.

The Phase I prototype system used map display capabilities in the **Create Manuscript**, **View Map**, **Edit Map**, and **Explain Manuscript** applications. **Create Manuscript** used map display to provide visual feedback of the progress of manuscript creation. In the Phase II MSPES the map display capability of the **Create Manuscript** application was replaced with an iconic clock face to indicate the approximate nearness to completion of manuscript creation. This reduces the amount of context switching between the system components involved in the **Create Manuscript** application and improves manuscript creation performance. The View Map, Edit Map, and Explain Manuscript capabilities of the prototype system caused confusion for users who wanted to invoke another application's capabilities while a different application's map display was on the screen. During Phase II, the Explain Manuscript and Edit Map applications were incorporated as user-selected 'modes' of the View Map application. Using the 'grayed out' user feedback mechanism, these modes are only available when appropriate. For example, explain mode is available only when a manuscript is being displayed and not while edit mode is active. Now, if while viewing a manuscript the user wants to see an explanation from the inference system of the rule base logic that led to a minefield likelihood categorization, the user clicks on the EXPLAIN button. This causes the inference system to be primed and an explanation window appears. Clicking on a manuscript location causes the inference system to re-evaluate the specified position and permits the user to interact directly with the inference system via the explanation window. This situation is illustrated in figure 3-7.

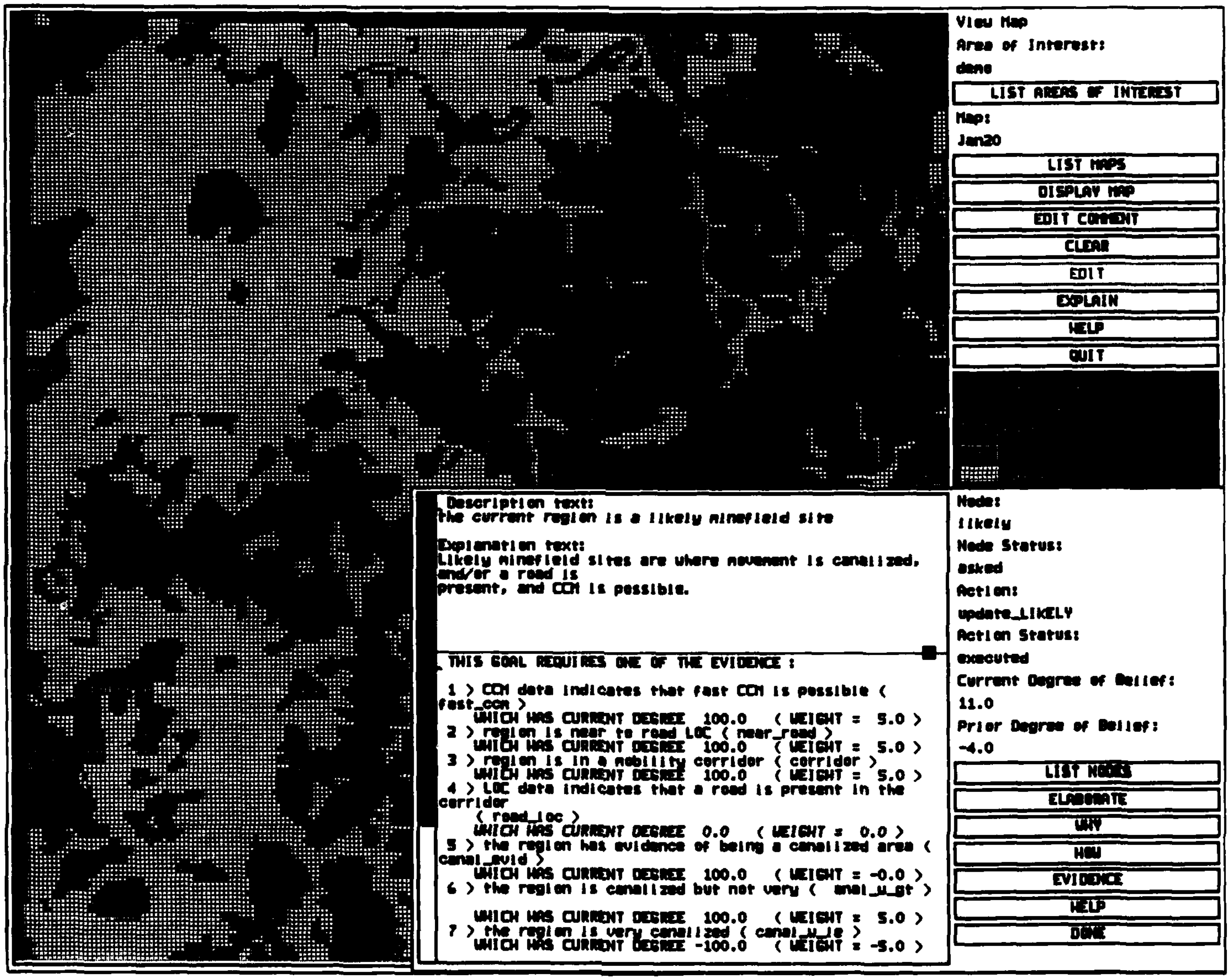


Figure 3-7 Explanation Mode of the View Map application

4. Evaluation and Recommendations

The following discussion focuses on evaluation of the Phase II developments and the recommendations for Phase III

• The implementation of the user interface using the X Window System substantially enhanced the portability of the MSPES. Under Phase III it is recommended that the user interface be implemented in DECwindows on the target system, a VAXStation II/GPX. DECwindows is Digital Equipment Corporation's implementation of the X Window System. DECwindows preserves the functional baseline and portability of the X Window System, but its X Window server is optimized for the VAX/VMS environment and its widget set implements the DECwindows 'look and feel'.

• The addition of some graphic functions would enhance the MSPES. These graphic functions should support simultaneous viewing of terrain overlays, a more flexible magnification function to provide zooming and panning, and overlay of reference grids.

• Preliminary evaluation of the QUILT software for movement from the Unix-based MSPES version to the VMS operating system on the VAXStation GPX has revealed some problems. There will need to be some additional investigation of the QUILT code to identify the extent that QUILT will have to be modified to operate under VMS. This is being treated as a top priority task to identify the extent of work required and the impact of these modifications on system performance under VMS.

• Evaluation of the inferencing capabilities and the rule base has been difficult because of the data <-> doctrine discrepancy. The experts concur that to evaluate the performance of rules of Soviet minefield doctrine for the European scenario over Korean terrain is unrealistic. It is recommended that European terrain data is used or terrain data from an area that more closely approximates European terrain. To date, ETL has had problems in providing the MSPES with data.

• Discussions with experts at the end of Phase II have again underscored the importance of expert and user analyst involvement during the development of this system. It is recommended that there be greater involvement of experts and the target user group in guiding the development of the knowledge base and the system parameters.

• Based on the expert interviews under Phase II, the perspective of the current rule base and inference structure should be reviewed and revised. Instead of basing the rules on a 'one CCM product at a time' processing perspective, a more realistic perspective may be to profile a task force and to base the perspective of the rules on making inferences on the task force movement across the terrain.

• Data input to the MSPES should be expanded, if possible, to accommodate the data and information that the minefield experts use such as elevation and line-of-site data.

Appendix A - List of References

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Zhang, T.Y.,and Suen, C.Y.; A Fast Thinning Algorithm for Thinning Digital Patterns; Communications of the ACM, Vol 27, No. 3; March 1984.

Appendix B - Terms and Abbreviations

CCM	Cross Country Movement
CVL	Computer Vision Laboratory. Refers to a raster data format used as the input format for QUILT areal quadtrees.
DEC	Digital Equipment Corporation
DMA	Defense Mapping Agency
ERS	Embedded Rule-Based System
ETL	U.S. Army Engineer and Topographic Laboratories
GIS	Geographic Information System
GPX	A trademark of DEC, a Graphics Accelerator chip set.
i/o	input/output
MIT	Massachusetts Institute of Technology
MSPES	Minefield Site Prediction Expert System
PGSC	PAR Government Systems Corporation
PM	Polygonal Map, a type of quadtree used to store linear data.
QUILT	A GIS developed by the University of Maryland Center for Automation Research.
SunOS	A trademark of Sun Microsystems Inc., the operating system used for the prototype and Phase II MSPES.
toolkit	A set of functions to simplify the development of application user interfaces.
UNIX	A trademark of AT&T Bell Laboratories, a multi-processing computer operating system
VAX	A trademark of DEC, standing for Virtual Address eXtension, describes a family of 32 bit super-minicomputer
VMS	A trademark of DEC, standing for Virtual Memory System, a high performance operating system that runs on the VAX family of computers.
widget	A user interface component in X11 with associated input and output semantics that implements a particular direct manipulation user interface style.
X11	A trademark of MIT, the X Window System

Appendix C - Phase II Rule Base One

This appendix contains the source listing of the terrain factor rulebase for the Phase II MSPES. An explanation of the ERS rule description syntax can be found in the *ERS User Manual* [Barth and Quinn-Jacobs, 1988]

The ERS rule base source listing contains commentary describing the logic as well as the inference network description. Following the rule base source listing, the reader will find output from the ERS 'print' command which formats ERS rule bases into a more traditional, IF ... THEN, form. This form may provide additional insight into the rule base logic for readers unfamiliar with ERS's rule description syntax.

```
RuleBase   Minefields
Version    2.1

; Tom Slack, 18 Oct 1988
; This version of the minefield site prediction is designed to go with
; a second rulebase which completes the evaluation based on battle management
; information.  This rule base does not handle the very likely case nor the
; unlikely case. It also no longer considers the size of a Quad region as a
; discriminator.
;
;Notes:
;       - Slow and very slow make no distinguishable difference.
;       - The concept of canalized is not built in, i.e., there is a
;         separate boolean function for that purpose rather than
;         using the <5 km knowledge.
;       - Raising and lowering the level of the threshold between
;         Likely and Possible can be done by simply changing the
;         Prior on the node Likely and perhaps changing the context of
;         on the node Likely.
;
;       Evid Function  ERS type     Description
;
;       ___________    _________    ____________
;       ccm_class      numerical    returns integer 1 - 7 indicating
;                                   ccm type of the quad
;       road_within_3km     logical      returns yes if distance in kilometers
;                                   to nearest road loc-containing-quad
;                                   is less then 3
;       mobility_corr  logical      returns YES if quad belongs to a
;                                   mobility corridor
;       loc_in_corr    logical      returns yes if loc is in the mobility
;                                   corridor that the quad belongs to
;       canalized      logical      returns yes if the quad is in a
;                                   canalized part of the mobility corridor
;                                   it belongs to.
;       canal_width    numerical    returns the width in km  of the
;                                   canalized part of the mobility corridor
;                                   that the quad belongs to.
```

```
;
; Based on a rulebase by J. Doughty, 13 Jan 1988
;
; Based on concept demo rulebase by S. Barth, 28 April 1987
; which was based on an initial rule base built by O. Long, November '86
; and on a flow chart by A. Downs, April '87
;
; The purpose of this rule base is to determine the likelihood of a
; minefield being present at a certain site.
;
; The actions that are fired when a goal is reached will update a
; minefield site prediction manuscript with the goal value for that area.

ActionSet    GoalActions    5.0 Any

InitialGoal    unevaluated

; The goal "unevaluated" has simple criteria, and
; the other 2 goals, "possible", and "likely", will be
; considered only when these criteria are not met.
; "Likely" is treated as a sub-category of possible;
; i.e., every likely site is also a possible site. Therefore, for whatever
; evidence is present, db(likely) <= db(possible),
; (db stands for degree of belief).

node unevaluated
   member   GoalActions
   action   update_UNEVAL
   text desc
      " more data is needed to evaluate the current region "
   elaboration
      "  a region is unevaluated if its CCM class indicates movement is not
possible or if it is a built up area "
   explanation
      "  a region is not evaluated as to the likelihood its being a
minefield site if its CCM class indicates movement is not possible or if it
is a built up area "
   inference
      prior -5.0
      logical antecedents or ( no_go no_go_water built_up )
      control
            goal

node possible
   member   GoalActions
   action   update_POSSIBLE
   text desc
      " the current region is a possible minefield site"
   elaboration
      " possible minefield sites are regions where a minefield MIGHT be
located"
   explanation
      " Nearly everything is a possible minefield site, unless it's
```

```
an unevaluated area. "
   inference
       prior 0.0
       bayesian antecedents (
              ccm_possible pw  6.0          nw -1.0
              fast_ccm     pw  5.0          nw  0.0
              near_road    pw  5.0          nw  0.0
              corridor     pw  5.0          nw  0.0
              road_loc     pw  5.0          nw  0.0
              canal_w_gt   pw  5.0          nw  0.0
              canal_w_le   pw 10.0          nw  0.0
              )
       control
              context of unevaluated int min 0.0
              goal

; For the likely goal, antecedent weights were assigned with the idea that
; if all three conditions are present we want db 20, if only ccm_possible
; and road_loc are present we'll say db 10, if ccm_possible and canal_area,
; but there's no road, db 10. If only ccm_possible occurs then db 0
; (50% chance)
; The other cases don't occur, since we use ccm_possible as context.
;
node likely
   member   GoalActions
   action   update_LIKELY
   text desc
       " the current region is a likely minefield site"
   elaboration
       " CCM is possible and movement is canalized or a road is present in
regions that are likely minefield sites"
   explanation
       " Likely minefield sites are where movement is canalized, and/or
       a road is present, and CCM is possible. "
   inference
       prior -4.0
       bayesian antecedents
              (
              fast_ccm     pw  5.0          nw -5.0
              near_road    pw  5.0          nw  0.0
              corridor     pw  5.0          nw  0.0
              road_loc     pw  5.0          nw -2.0
              canal_evid   pw  0.0          nw -3.0
              canal_w_gt   pw  5.0          nw  0.0
              canal_w_le   pw 10.0          nw -5.0
              )
   control
       goal
       context of possible int 20.0 max

;______________________________________________________________________
; Intermediate Hypotheses
;
```

```
; Any category for CCM, except no-go's or built-up is considered as
; possible
;
node ccm_possible
   text desc
      " CCM data indicates that movement is possible in the current region"
   elaboration
      " CCM movement is possible in regions that are classified as 'go',
      'restricted', 'slow', or 'very slow'."
   inference
            prior -10.0
            logical antecedents or ( go restricted slow very_slow )

node fast_ccm
   text desc
      " CCM data indicates that fast CCM is possible"
   elaboration
      " CCM data indicates that the region is Go (1) or Restricted (2) -
      possible tank speeds are above 15 km/hr. "
      inference
            prior -10.0
            logical antecedents or ( go restricted )

; ________________________________________________________________
; Evidence Nodes
;
node corridor
    text desc
      " region is in a mobility corridor"
    explanation
      " Skeletization indicates this is part of a mobilty corridor"
    inference
      prior -10.0
      test mobility_corr

node near_road
    text desc
      " region is near to road LOC"
    explanation
      " LOC data indicates a road is within 3 km"
    inference
      prior -10.0
      test road_within_3km

node road_loc
      text desc
      " LOC data indicates that a road is present in the corridor "
      elaboration
      " LOC data includes roads, railroads, power lines, and other
      man-made lines of communication."
      inference
            prior 0.0
      test loc_in_corr
```

```
    control
        context of corridor int 0.0 max

node canal_evid
    text desc
        " the region has evidence of being a canalized area"
    explanation
        " CCM data indicates the region has characteristics of a
canalized area "
    inference
        prior -10.0
        test canalized
    control
        context of corridor int 0.0 max

; SWB 20 Oct. 1987 - a choice node with primitive, this eliminates
; having to have each node for a set of mutually exclusive function results
; call the same primitive function. With the "test ccm_class" added to
; the choice node, ccm_class is called once, and the resulting value is
; compared to the specified answers.

choicenode canal_width
    text desc
        format specify exclusive
        " the canalization width of this area in kilometers"
    test canal_width
    inference
        prior 0.0
        answers
            <= 2.0  : ( canal_w_le )
            > 2.0   : ( canal_w_gt )
    control
        notgoal
        context of canal_evid int 0.0 max

node canal_w_le
    text desc
        " the region is very canalized"
    explanation
        " region has a canalization  width <= 2 km"
    inference
        prior 0.0

node canal_w_gt
    text desc
        " the region is canalized but not very"
    explanation
        " region has a canalization width > 2 km"
    inference
        prior 0.0

choicenode ccm
    text desc
```

```
      format specify exclusive
      " the CCM category of this area"
   test ccm_class
   inference
      prior 0.0
      answers
         = 1.0    : ( go )
         = 2.0    : ( restricted )
         = 3.0    : ( slow )
         = 4.0    : ( very_slow )
         = 5.0    : ( no_go )
         = 6.0    : ( no_go_water )
         = 7.0    : ( built_up )
       control
         notgoal

node go
    text desc
       " region is a go area "
    explanation
       " The region can support speeds greater than 30.0 km/hr"
    inference
       prior -10.0

node restricted
    text desc
       " region is restricted "
    explanation
       " The region allows speeds between 15.0 and 30.0 km/hr"
    inference
       prior -10.0

node slow
    text desc
       " region is a slow travel area "
    explanation
       " The region permits speeds between 5.0 and 15.0 km/hr"
    inference
       prior -10.0

node very_slow
    text desc
       " region is a very slow travel area "
    explanation
       " The region permits speeds bewteen 1.5 and 5.0 km/hr"
    inference
       prior -10.0

node no_go
    text desc
       " region is no go"
    explanation
       " The region permits speeds less than 1.5 km/hr"
```

```
    inference
        prior -5.0

node no_go_water
    text desc
        " region is no go - open water"
    explanation
        " The region contains open water that cannot be crossed"
    inference
        prior -10.0

node built_up
    text desc
        " region is built up"
    explanation
        " CCM category for battle tank is 7 - BUILT UP AREA "
    inference
        prior -10.0

stop
```

Following is the output from ERS's print command for Phase 2 Rule Base One. Text in parenthesis refers to inference network internals.

RuleBase Minefields Version 2.1

```
IF    region is no go ( no_go )
      ccm_class =  5.0
   OR
      region is no go - open water ( no_go_water )
      ccm_class =  6.0
   OR
      region is built up ( built_up )
      ccm_class =  7.0
THEN
      more data is needed to evaluate the current region  ( unevaluated )


IF    CCM data indicates that movement is possible in the current region
      ( ccm_possible )
THEN  (PW=  6.0 NW=  -1.0 W=  -1.0)
      the current region is a possible minefield site ( possible )
      WITHIN THE CONTEXT OF ( INT -100.0,  0.0 )
      more data is needed to evaluate the current region  ( unevaluated )


IF     CCM data indicates that fast CCM is possible ( fast_ccm )
THEN  (PW=  5.0 NW=  0.0 W=  -0.0)
      the current region is a possible minefield site ( possible )
      WITHIN THE CONTEXT OF ( INT -100.0,  0.0 )
      more data is needed to evaluate the current region  ( unevaluated )


IF     region is near to road LOC ( near_road )
      road_within_3km
THEN  (PW=  5.0 NW=  0.0 W=  5.0)
      the current region is a possible minefield site ( possible )
      WITHIN THE CONTEXT OF ( INT -100.0,  0.0 )
      more data is needed to evaluate the current region  ( unevaluated )


IF     region is in a mobility corridor ( corridor )
      mobility_corr
THEN  (PW=  5.0 NW=  0.0 W=  -0.0)
      the current region is a possible minefield site ( possible )
      WITHIN THE CONTEXT OF ( INT -100.0,  0.0 )
      more data is needed to evaluate the current region  ( unevaluated )


IF     LOC data indicates that a road is present in the corridor
      ( road_loc )
```

```
      loc_in_corr
      WITHIN THE CONTEXT OF ( INT  0.0,  100.0 )
      region is in a mobility corridor ( corridor )
THEN   (PW=   5.0 NW=   0.0 W=   0.0)
      the current region is a possible minefield site ( possible )
      WITHIN THE CONTEXT OF ( INT -100.0,  0.0 )
      more data is needed to evaluate the current region  ( unevaluated )


IF     the region is canalized but not very ( canal_w_gt )
      canal_width >   2.0
THEN   (PW=   5.0 NW=   0.0 W=   5.0)
      the current region is a possible minefield site ( possible )
      WITHIN THE CONTEXT OF ( INT -100.0,  0.0 )
      more data is needed to evaluate the current region  ( unevaluated )


IF     the region is very canalized ( canal_w_le )
      canal_width <=   2.0
THEN   (PW=  10.0 NW=   0.0 W=  -0.0)
      the current region is a possible minefield site ( possible )
      WITHIN THE CONTEXT OF ( INT -100.0,  0.0 )
      more data is needed to evaluate the current region  ( unevaluated )


IF     region is a go area  ( go )
      ccm_class =   1.0
   OR
      region is restricted  ( restricted )
      ccm_class =   2.0
   OR
      region is a slow travel area  ( slow )
      ccm_class =   3.0
   OR
      region is a very slow travel area  ( very_slow )
      ccm_class =   4.0
THEN
      CCM data indicates that movement is possible in the current region
      ( ccm_possible )


IF     region is a go area  ( go )
      ccm_class =   1.0
   OR
      region is restricted  ( restricted )
      ccm_class =   2.0
THEN
      CCM data indicates that fast CCM is possible ( fast_ccm )


IF     CCM data indicates that fast CCM is possible ( fast_ccm )
THEN   (PW=   5.0 NW=  -5.0 W=  -5.0)
      the current region is a likely minefield site ( likely )
```

WITHIN THE CONTEXT OF (INT 20.0, 100.0)
the current region is a possible minefield site (possible)
WHICH REQUIRES THE CONTEXT OF (INT -100.0, 0.0)
more data is needed to evaluate the current region
(unevaluated)

IF region is near to road LOC (near_road)
road within 3km
THEN (PW= 5.0 NW= 0.0 W= 5.0)
the current region is a likely minefield site (likely)
WITHIN THE CONTEXT OF (INT 20.0, 100.0)
the current region is a possible minefield site (possible)
WHICH REQUIRES THE CONTEXT OF (INT -100.0, 0.0)
more data is needed to evaluate the current region
(unevaluated)

IF region is in a mobility corridor (corridor)
mobility_corr
THEN (PW= 5.0 NW= 0.0 W= -0.0)
the current region is a likely minefield site (likely)
WITHIN THE CONTEXT OF (INT 20.0, 100.0)
the current region is a possible minefield site (possible)
WHICH REQUIRES THE CONTEXT OF (INT -100.0, 0.0)
more data is needed to evaluate the current region
(unevaluated)

IF LOC data indicates that a road is present in the corridor
(road_loc)
loc_in_corr
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
region is in a mobility corridor (corridor)
THEN (PW= 5.0 NW= -2.0 W= 0.0)
the current region is a likely minefield site (likely)
WITHIN THE CONTEXT OF (INT 20.0, 100.0)
the current region is a possible minefield site (possible)
WHICH REQUIRES THE CONTEXT OF (INT -100.0, 0.0)
more data is needed to evaluate the current region
(unevaluated)

IF the region has evidence of being a canalized area (canal_evid)
canalized
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
region is in a mobility corridor (corridor)
THEN (PW= 0.0 NW= -3.0 W= 0.0)
the current region is a likely minefield site (likely)
WITHIN THE CONTEXT OF (INT 20.0, 100.0)
the current region is a possible minefield site (possible)
WHICH REQUIRES THE CONTEXT OF (INT -100.0, 0.0)
more data is needed to evaluate the current region

(unevaluated)

IF the region is canalized but not very (canal_w_gt)
canal_width > 2.0
THEN (PW= 5.0 NW= 0.0 W= 5.0)
the current region is a likely minefield site (likely)
WITHIN THE CONTEXT OF (INT 20.0, 100.0)
the current region is a possible minefield site (possible)
WHICH REQUIRES THE CONTEXT OF (INT -100.0, 0.0)
more data is needed to evaluate the current region
(unevaluated)

IF the region is very canalized (canal_w_le)
canal_width <= 2.0
THEN (PW= 10.0 NW= -5.0 W= -5.0)
the current region is a likely minefield site (likely)
WITHIN THE CONTEXT OF (INT 20.0, 100.0)
the current region is a possible minefield site (possible)
WHICH REQUIRES THE CONTEXT OF (INT -100.0, 0.0)
more data is needed to evaluate the current region
(unevaluated)

PARENT: the canalization width of this area in kilometers (canal_width)
(THIS IS A GROUPING STRUCTURE AND DOES NOT REPRESENT ANY RULES.)

PARENT: the CCM category of this area (ccm)
(THIS IS A GROUPING STRUCTURE AND DOES NOT REPRESENT ANY RULES.)

Appendix D - Phase II Rule Base Two

This appendix contains the source listing of the enemy intention and battlefield situation rulebase for the Phase II MSPES. An explanation of the ERS rule description syntax can be found in the *ERS User Manual* [Barth and Quinn-Jacobs, 1988]

The ERS rule base source listing contains commentary describing the logic as well as the inference network description. Following the rule base source listing, the reader will find output from the ERS 'print' command which formats ERS rule bases into a more traditional, IF...THEN, form. This form may provide additional insight into the rule base logic for readers unfamiliar with ERS's rule description syntax.

```
RuleBase    Mines_II

Version     2.2


; Tom Slack, 24 Oct 1988
; This version of the minefield site prediction is designed to go with
; a previous rulebase which evaluates areas based on terrain data.
; This rule base uses the results of that evaluation as evidence.
;
; Evidence functions used are:
;
;       Evid Function ERS type     Description
;       ____________  ________     ___________
;       rb1_likely    logical      Returns true if rb1 said likely. Since
;                                  quads that are not at least possible
;                                  are not passed to this rb, other if
;                                  this is false, then possible is
;                                  assumed.
;       corridor      logical      Returns true if this is a mobility
;                                  corridor.
;       ave_attack    logical      Returns true if this is an avenue of
;                                  attack. An avenue of attack is a
;                                  mobility corridor that has been marked
;                                  in the preprocessing step. If the
;                                  position of the enemy is unknown, then
;                                  the entire map is processed, and all
;                                  corridors near your own position
;                                  should be marked as avenues.
;       posture       string       The enemy posture: A-Attacking,
;                                  D-Defending.
;       mci_d         numerical    The distance in km to the nearest
;                                  intersection of mobility corridors.
;                                  This data is only requested when the
;                                  current quad is in a corridor.
;       loc_d         numerical    The distance in km to the nearest road
```

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;                                   or railroad.
;       loci_d        numerical     The distance in km to the nearest
;                                   intersection of roads or road and
;                                   railroad.
;       ins_d         numerical     The distance in km to the nearest key
;                                   installation.
;       occupied      logical       Returns true if quad has been behind or
;                                   suspected to have been behind the enemy
;                                   FLOT in the last 72 hours.  If the
;                                   enemy position has been unknown for
;                                   this period this should always return
;                                   true.
;       artillery     logical       Returns true if artillery is suspected
;                                   to be in this quad.  This data is only
;                                   requested when occupied is true.
;       obstruction   logical       Is there evidence of man made
;                                   obstructions.  This data is only
;                                   requested when occupied is true.
;       poz           logical       Is there evidence of podrazdelenyie.
;                                   This data is only requested when
;                                   occupied is true.

ActionSet    GoalActions    5.0 Any

InitialGoal    possible

node possible
   member    GoalActions
   action    update_POSSIBLE
   text desc
       " the current area is a possible minefield site"
      explanation
       " Every area evaluated will have been determined to be possible by
       prior screening. The degree of belief for the site continuing to be
       possible may be increased or reduced according to the factors below. "
   inference
       prior 6.0
       bayesian antecedents (
               likely_evid    pw  3.0          nw  0.0
               mc_site              pw  7.0          nw  0.0
               key            pw 11.0          nw  0.0
               e_activity     pw 15.0          nw  0.0
               )
       control
               goal

node likely
   member    GoalActions
   action    update_LIKELY
   text desc
       " the current area is a likely minefield site"
   inference
       prior -7.0
```

```
        bayesian antecedents
                (
                likely_evid    pw  3.0          nw  0.0
                mc_site        pw  7.0          nw  0.0
                key            pw 11.0          nw  0.0
                e_activity     pw 15.0          nw  0.0
                )
    control
        goal
        context of possible int 17.0 max

node very
    member    GoalActions
    action    update_VERY
    text desc
        " the current area is a very likely minefield site"
    explanation
        " The presence of artillery or important installations, or some
        combinations of enemy posture and mobility corridors may indicate
        that the current area is very likely to be mined."
    inference
        prior -20.0
        bayesian antecedents
                (
                likely_evid    pw  3.0          nw  0.0
                mc_site        pw  7.0          nw  0.0
                key            pw 11.0          nw  0.0
                e_activity     pw 15.0          nw  0.0
                )
    control
        goal
        context of likely int 17.0 max

;
;______________________________________________________________
; Intermediate Hypotheses
;

node mc_site
    text desc
        " mobility corridor information indicates that mines are likely in
        the current area"
        explanation
        " The relationship of the current area to known mobility corridors,
        and enemy posture indicate whether minefields are likely. "
    inference
        prior 0.0
        bayesian antecedents
                (
                mobility       pw  1.0          nw  0.0
                mc_inter       pw  2.0          nw  0.0
                ave_defend     pw  4.0          nw  0.0
                )
    control
```

```
        context of mobility int prior max

node ave_defend
    text desc
        " the current area lies in an avenue of approach that is being
        defended by the enemy "
    inference
        prior 0.0
        logical antecedents and ( avenue defend )

node key
    text desc
        " a key feature is nearby"
    explanation
        " Mines are likely to be placed near key features such as roads,
        railroads, intersections of roads and railroads, and key installations
        such as airfields."
    inference
        prior 0.0
        logical antecedents or ( loc_v_close near_inter install      loc_in_cor )

node loc_in_cor
    text desc
        " current area is in a corridor with a loc nearer than 1 km "
    inference prior 0.0
        logical antecedents and ( loc_near )
    control context of mobility int prior max

node e_activity
    text desc
        " enemy activity indicates possible mines"
        explanation
        " Mines are more likely where the enemy has had a chance to place them,
        especially in areas covered by artillery, and complementing other
        obstructions."
    inference
        prior 0.0
        bayesian antecedents
                (
                occupied      pw  1.0            nw  0.0
                obstruction   pw  2.0            nw  0.0
                poz           pw  4.0            nw  0.0
                artillery     pw  8.0            nw  0.0
                )
    control
        context of occupied int prior max


;_______________________________________________________________
; Evidence Nodes
;

choicenode posture
```

```
    text desc
        format specify exclusive
        " the posture of the enemy"
    elaboration
        " Defensive posture makes minefields more likely along an avenue of
        approach. Attack posture makes minefields less likely. "
    test posture
    inference prior 0.0
        answers
            " a" : ( attack )
            " d" : ( defend )
    control notgoal

node attack
    text desc
        " attack "
    explanation
        " Enemy forces are postured for an attack "
    inference
        prior 0.0

node defend
    text desc
        " defend "
    explanation
        " Enemy forces are postured for defense "
    inference
        prior 0.0


choicenode LOC_dist
    text desc format specify related
        " the distance to a LOC segment"
    explanation
        " Mines are often placed near a loc."
    test loc_d
    inference prior 0.0
        answers
            <= 1.0 : ( loc_near )
            <= 0.5 : ( loc_close )
            <= 0.2 : ( loc_v_close )
    control notgoal

node loc_near
    text desc
        " the current area is near a LOC segment"
        elaboration
        " 'near' is defined as within 1.0 km. "
    inference
        prior 0.0

node loc_close
    text desc
```

```
        " the current area is close to a LOC segment"
        elaboration
        " 'close' is defined as within 0.5 km. "
    inference
        prior 0.0

node loc_v_close
    text desc
        " the current area is very close to an LOC segment"
        elaboration
        " 'very close' is defined as within 0.2 km. "
    inference
        prior 0.0

node likely_evid
    text desc
        " the current area is called likely by the terrain rule base"
    explanation
        " This is rule base II; rule base I runs first and marks some areas
        as likely."
    inference
        prior 0.0
        test rb1_likely

node mobility
    text desc
        " the current area is in a mobility corridor "
    explanation
        " If this is a mobility corridor many other evidence should be
        considered."
    inference
        prior 0.0
    test corridor

node avenue
    text desc
        " the current area is in an avenue of approach "
        explanation
        " Minefield sites are likely in avenues of approach that the enemy is
        defending. "
    inference
        prior 0.0
    test ave_attack

node mc_inter
    text desc
        " the current area is near an intersection of corridors"
    explanation
        " Within 2 km of an intersection of corridors is a likely mine site."
    inference
        prior 0.0
    test mci_d <= 2.0
```

```
node near_inter
   text desc
      " the current area is near an intersection of locs"
   explanation
      " Within 0.5 km of an intersection of roads or railroads is a likely
      mine site."
    inference
      prior 0.0
   test loci_d <= 0.5
   control
      context of loc_close int prior max

node install
   text desc
      " the current area is near a key installation"
   explanation
      " Within 5 km of a key installation is a likely mine site."
    inference
      prior 0.0
   test ins_d <= 5.0

node occupied
   text desc
      " the current area has been behind the enemy FLOT in the last 72 hours"
   explanation
      " Previously occupied areas are more likely to be mined."
    inference
      prior 0.0
   test occupied

node artillery
   text desc
      " the current area has evidence of artillery support"
   explanation
      " Since mines often support artillery, artillery presence is a good
      indicator."
    inference
      prior 0.0
   test artillery

node obstruction
   text desc
      " the current area has evidence of man made obstacles"
   explanation
      " Since mines are designed to slow down and modify patterns of
      mobility, the presence of other means to accomplish this, such as
      obstacles, is an positive indicator."
    inference
      prior 0.0
   test obstruction

node poz
   text desc
```

```
        " the enemy forces have access to podrazdelenyie "
    explanation
        " Such equipment allows the rapid laying of mines."
     inference
        prior 0.0
    test poz

stop
```

Following is the output from ERS's print command for Phase 2 Rule Base Two. Text in parenthesis refers to inference network internals.

RuleBase Mines_II Version 2.2

IF the current area is called likely by the terrain rule base
(likely_evid)
rb1_likely
THEN (PW= 3.0 NW= 0.0 W= 0.0)
the current area is a possible minefield site (possible)

IF mobility corridor information indicates that mines are likely in the
current area (mc_site)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area is in a mobility corridor (mobility)
THEN (PW= 7.0 NW= 0.0 W= 0.0)
the current area is a possible minefield site (possible)

IF a key feature is nearby (key)
THEN (PW= 11.0 NW= 0.0 W= 0.0)
the current area is a possible minefield site (possible)

IF enemy activity indicates possible mines (e_activity)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area has been behind the enemy FLOT in the last 72 hours
(occupied)
THEN (PW= 15.0 NW= 0.0 W= 0.0)
the current area is a possible minefield site (possible)

IF the current area is in a mobility corridor (mobility)
corridor
THEN (PW= 1.0 NW= 0.0 W= 0.0)
mobility corridor information indicates that mines are likely in the
current area (mc_site)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area is in a mobility corridor (mobility)

IF the current area is near an intersection of corridors (mc_inter)
mci_d <= 2.0
THEN (PW= 2.0 NW= 0.0 W= -0.0)
mobility corridor information indicates that mines are likely in the
current area (mc_site)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area is in a mobility corridor (mobility)

IF the current area lies in an avenue of approach that is being defended by the enemy (ave_defend)
THEN (PW= 4.0 NW= 0.0 W= -0.0)
mobility corridor information indicates that mines are likely in the current area (mc_site)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area is in a mobility corridor (mobility)

IF the current area is in an avenue of approach (avenue)
ave_attack
AND
defend (defend)
posture
THEN
the current area lies in an avenue of approach that is being defended by the enemy (ave_defend)

IF the current area is very close to an LOC segment (loc_v_close)
loc_d <= 0.0
OR
the current area is near an intersection of locs (near_inter)
loci_d <= 0.0
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area is close to a LOC segment (loc_close)
OR
the current area is near a key installation (install)
ins_d <= 5.0
OR
current area is in a corridor with a loc nearer than 1 km (loc_in_cor)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area is in a mobility corridor (mobility)
THEN
a key feature is nearby (key)

IF the current area is near a LOC segment (loc_near)
loc_d <= 1.0
THEN
current area is in a corridor with a loc nearer than 1 km (loc_in_cor)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area is in a mobility corridor (mobility)

IF the current area has been behind the enemy FLOT in the last 72 hours (occupied)
occupied
THEN (PW= 1.0 NW= 0.0 W= 0.0)
enemy activity indicates possible mines (e_activity)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)

the current area has been behind the enemy FLOT in the last 72 hours
(occupied)

IF the current area has evidence of man made obstacles (obstruction)
obstruction
THEN (PW= 2.0 NW= 0.0 W= 0.0)
enemy activity indicates possible mines (e_activity)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area has been behind the enemy FLOT in the last 72 hours
(occupied)

IF the enemy forces have access to podrazdelenyie (poz)
poz
THEN (PW= 4.0 NW= 0.0 W= 0.0)
enemy activity indicates possible mines (e_activity)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area has been behind the enemy FLOT in the last 72 hours
(occupied)

IF the current area has evidence of artillery support (artillery)
artillery
THEN (PW= 8.0 NW= 0.0 W= 0.0)
enemy activity indicates possible mines (e_activity)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area has been behind the enemy FLOT in the last 72 hours
(occupied)

IF the current area is called likely by the terrain rule base
(likely_evid)
rb1_likely
THEN (PW= 3.0 NW= 0.0 W= 0.0)
the current area is a likely minefield site (likely)
WITHIN THE CONTEXT OF (INT 17.0, 100.0)
the current area is a possible minefield site (possible)

IF mobility corridor information indicates that mines are likely in the
current area (mc_site)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area is in a mobility corridor (mobility)
THEN (PW= 7.0 NW= 0.0 W= 0.0)
the current area is a likely minefield site (likely)
WITHIN THE CONTEXT OF (INT 17.0, 100.0)
the current area is a possible minefield site (possible)

IF a key feature is nearby (key)
THEN (PW= 11.0 NW= 0.0 W= 0.0)
the current area is a likely minefield site (likely)

WITHIN THE CONTEXT OF (INT 17.0, 100.0)
the current area is a possible minefield site (possible)

IF enemy activity indicates possible mines (e_activity)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area has been behind the enemy FLOT in the last 72 hours (occupied)
THEN (PW= 15.0 NW= 0.0 W= 0.0)
the current area is a likely minefield site (likely)
WITHIN THE CONTEXT OF (INT 17.0, 100.0)
the current area is a possible minefield site (possible)

IF the current area is called likely by the terrain rule base (likely_evid)
rb1_likely
THEN (PW= 3.0 NW= 0.0 W= 0.0)
the current area is a very likely minefield site (very)
WITHIN THE CONTEXT OF (INT 17.0, 100.0)
the current area is a likely minefield site (likely)
WHICH REQUIRES THE CONTEXT OF (INT 17.0, 100.0)
the current area is a possible minefield site (possible)

IF mobility corridor information indicates that mines are likely in the current area (mc_site)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area is in a mobility corridor (mobility)
THEN (PW= 7.0 NW= 0.0 W= 0.0)
the current area is a very likely minefield site (very)
WITHIN THE CONTEXT OF (INT 17.0, 100.0)
the current area is a likely minefield site (likely)
WHICH REQUIRES THE CONTEXT OF (INT 17.0, 100.0)
the current area is a possible minefield site (possible)

IF a key feature is nearby (key)
THEN (PW= 11.0 NW= 0.0 W= 0.0)
the current area is a very likely minefield site (very)
WITHIN THE CONTEXT OF (INT 17.0, 100.0)
the current area is a likely minefield site (likely)
WHICH REQUIRES THE CONTEXT OF (INT 17.0, 100.0)
the current area is a possible minefield site (possible)

IF enemy activity indicates possible mines (e_activity)
WITHIN THE CONTEXT OF (INT 0.0, 100.0)
the current area has been behind the enemy FLOT in the last 72 hours (occupied)
THEN (PW= 15.0 NW= 0.0 W= 0.0)
the current area is a very likely minefield site (very)
WITHIN THE CONTEXT OF (INT 17.0, 100.0)

the current area is a likely minefield site (likely)
WHICH REQUIRES THE CONTEXT OF (INT 17.0, 100.0)
the current area is a possible minefield site (possible)

PARENT: the posture of the enemy (posture)
(THIS IS A GROUPING STRUCTURE AND DOES NOT REPRESENT ANY RULES.)

PARENT: the distance to a LOC segment (LOC_dist)
(THIS IS A GROUPING STRUCTURE AND DOES NOT REPRESENT ANY RULES.)